A GAS DYNAMICS GURNEY ANALYSIS FOR MODELING THE ACCELERATION HISTORY OF AN EXPLODING SYSTEM*

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ABSTRACT

The Gurney method was originally developed to estimate terminal velocities imparted to metals by explosives, and was subsequently used to correlate exploding foil system performance with firing circuit electrical parameters. The inclusion of internal energy in the explosive gas permits calculation of the acceleration history of the system. Comparison with experimental and hydrocode results indicates that proper selection of initial displacement, velocity, and the polytropic gas exponent can bring model and experimental results into close agreement.

I. INTRODUCTION

We want to make some remarks today on the use of the Gurney method to estimate the acceleration history of an exploding-foil-driven flyer. Schmidt, Seitz, and Wackerle[1] formulated the equation of motion for such a system with time dependent energy deposition. As McGlaun has shown, the approximation of uniform pressure and density throughout the foil gas can be replaced by a continuum solution which improves the overall accuracy. This modification could be added to the work I am presenting.

Today we want to discuss the governing differential equation (D.E.) of motion and mention some of the things we can learn from it. We want to discuss some things that the hydrocodes can tell us about solving the D.E. And, finally, we want to discuss some of the things we can learn from it. We want to discuss

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some of the things we can do with the D.E. that aren't so easy with the hydrocodes.

II. THE DIFFERENTIAL EQUATION

The D. E. of motion can be written in the form shown in Figure 1, which gives an expression for the acceleration of the flyer, $\ddot{x}$. We see that the driving term is the quantity in brackets. It is the difference between the input energy and the system kinetic energy and thus is the internal energy. In this loss-less model, we see all the input energy will be converted to kinetic energy in a long barrel.

The internal energy is multiplied by several factors. Generally we want rapid acceleration, so we want the multipliers to be large. The factor $\frac{1}{X}$ is large when flyer displacements are small. Thus, input energy is more rapidly converted to kinetic energy if inputed when X is small. The factor $\frac{G}{M}$ is the "charge to mass ratio". It is comforting to see that acceleration is greater for large charge/mass ratios. Likewise, $(1+A)^{-1}$ is largest when A is small corresponding to heavily tamped systems. Finally, the polytropic gas exponent, n, is a factor.

III. HYDROCODE

When Schmidt, Seitz, and Wackerle carried out the solution they used for n a value of 5/3 corresponding to the adiabatic gas constant for a monatomic gas. This leads to velocity-time results much higher than experiment. To bring results into agreement, they obtained an empirical correction factor for the power pulse illustrated schematically in Figure 2. The implication of this result is that early input energy does not contribute to flyer motion while late time energy input is used at full value. As we shall see there are other means to obtain agreement between experiment and the model.

We want to propose an alternate method for bringing this model into agreement, and it involves selection of different values for n and for the initial conditions for the D. E.

From CHART D one-dimensional hydrocode simulations, we looked for pressure-volume relationship in the expanding foil gas. CHART D has carefully constructed analytic equations of state for aluminum and copper which are valid over a large range of temperatures and densities and include solid, liquid, vapor, mixed phases and plasma. In CHART D simulations of foil/flyer systems, the P-V relationship after shut-off of input energy gave $n = 1.23$ for aluminum. To check this value, we used the E.O.S. portion of CHART D for aluminum which gave $1.3 < n < 1.4$ in the range of temperatures and densities of interest, which is close to the value obtained in the simulation.

IV. RESULTS

Figure 3 shows the effect of n on the gas dynamic Gurney velocity-time calculation for a flyer using the power pulse without empirical correction. Shown for comparison is CHART D result.

In addition to the polytropic gas constant, the hydrocode furnishes other useful information for solving the D.E. The above solutions assume $X_0 = X_0 = 0$. However, the D.E. applies to a gas dynamics problem. So it is appropriate to ask what are the initial conditions for the gas-dynamics problem. From CHART D runs, the foil has been heated to vaporization at a time when it has expanded about three-fold and the flyer has attained about ten percent of its impact velocity. Using these initial values, the D.E. solution is in close agreement with CHART D as shown in Figure 4.

These results apply to a small aluminum foil system. For contrast we can also look at a large copper system (Figure 5) and see that a similar n is appropriate and in Figure 6 a fair agreement can be produced with proper initial conditions.

All of these results are aimed at comparison between two models, gas dynamic Gurney D.E. and CHART D hydrocode. As has been pointed out before, using CHART D with measured power profiles over-predicts V(t). So, the D.E. method would also overpredict. We believe the problem lies in power measurements and we have an experimental program underway to attempt to improve the measurements.

V. GURNEY vs. HYDROCODE

In conclusion, let us comment on the use of the Gurney D.E. vs. hydrocodes. We think the D.E. offers several useful features.

1. The D.E. offers insight into trends and limiting cases.
2. The agreement obtained indicates wave-propagation effects are small, so the use of a hydrocode may be unnecessary.
3. Big codes on big computers are somewhat intimidating. The D.E. can be handled with less computer expertise and can be approximated with tabular or hand calculator techniques.
4. The D.E. is convenient for use with fire set circuit codes.

REFERENCES

1. S. C. Schmidt, W. L. Seitz, Jerry Wackerle, "An Empirical Model to Compute the Velocity Histories of Flyers Driven by Electrically Exploding Foils," LASL Report LA-6809, July, 1977.

GAS DYNAMICS GURNEY MODEL EQUATION OF MOTION

$$\ddot{X} = \frac{(n-1)}{(1+A)}\frac{G}{M}\frac{1}{X}\left[E(t) - \frac{\dot{X}^2}{2(CF)^2}\right]$$

where $X, \dot{X}, \ddot{X}$ = flyer displacement, velocity, acceleration

$E(t)$ = input energy per unit foil mass

G = foil mass

M = flyer mass

N = tamper mass

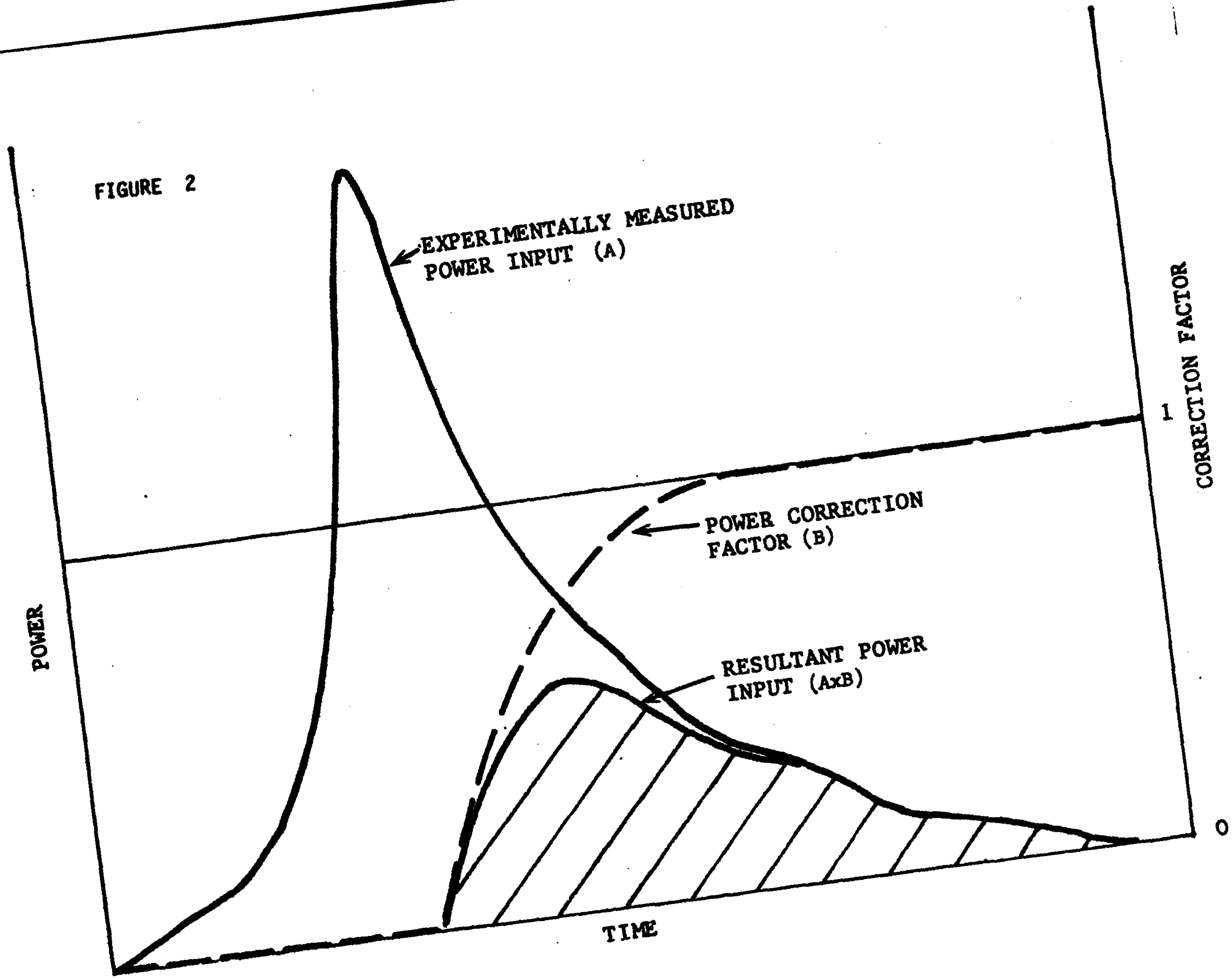
$A = \frac{G + 2M}{G + 2N}$

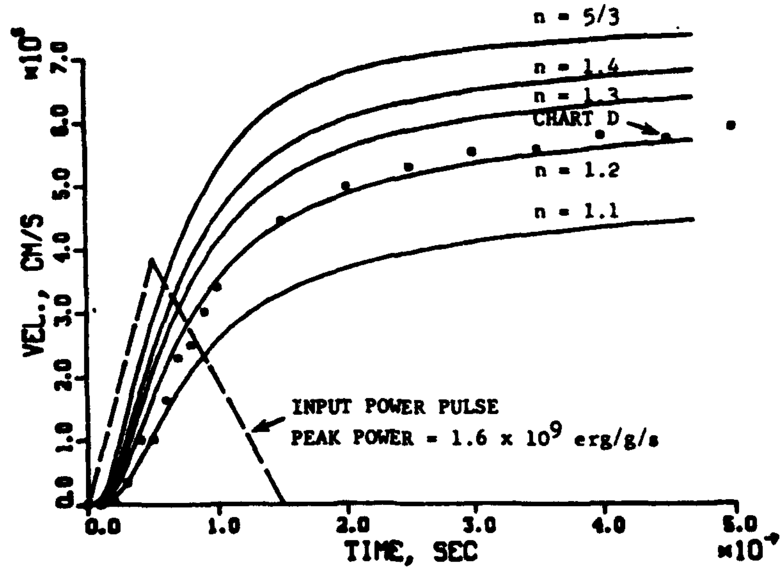
$(CF)^2 = \frac{G}{M + NA^2 + G(1 - A + A^2)}$

n = polytropic gas exponent

FIGURE 1

FIGURE 2


EXPERIMENTALLY MEASURED
POWER INPUT (A)
POWER CORRECTION
FACTOR (B)
RESULTANT POWER
INPUT (AxB)
POWER
CORRECTION FACTOR
1
0
TIME



FLYER 0.5 mm (2 mil) KAPTON

FOIL 0.01 mm (0.45 mil) ALUMINUM

TAMPER 0.76 mm (30 mil) MYLAR

FIGURE 3

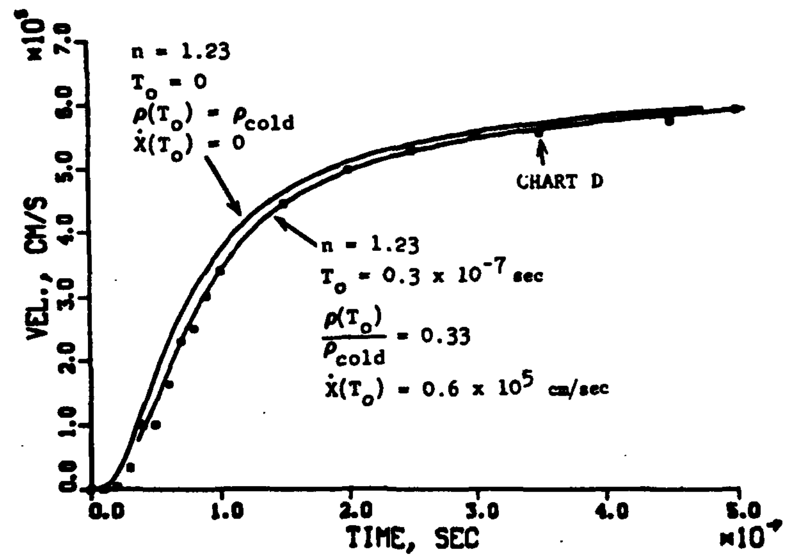
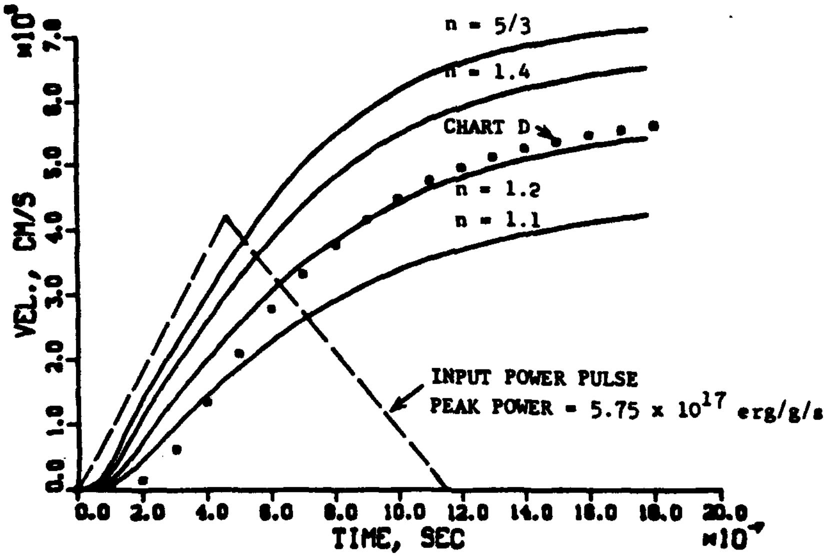


FIGURE 4



FLYER 0.18 mm (7 mil) KAPTON
FOIL 0.05 mm (2 mil) COPPER
TAMPER 0.76 mm (30 mil) MYLAR

FIGURE 5

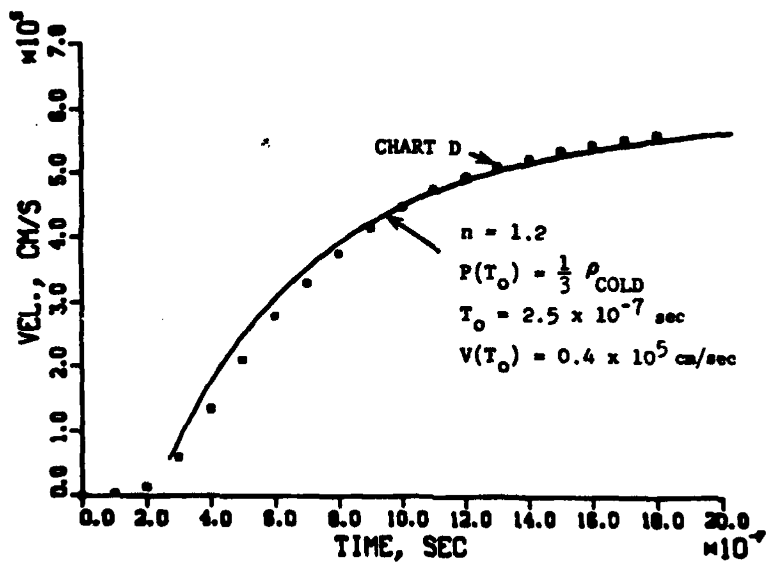


FIGURE 6